Multi-model Estimates of Atmospheric Response to Modes of SST Variability and Implications for Droughts

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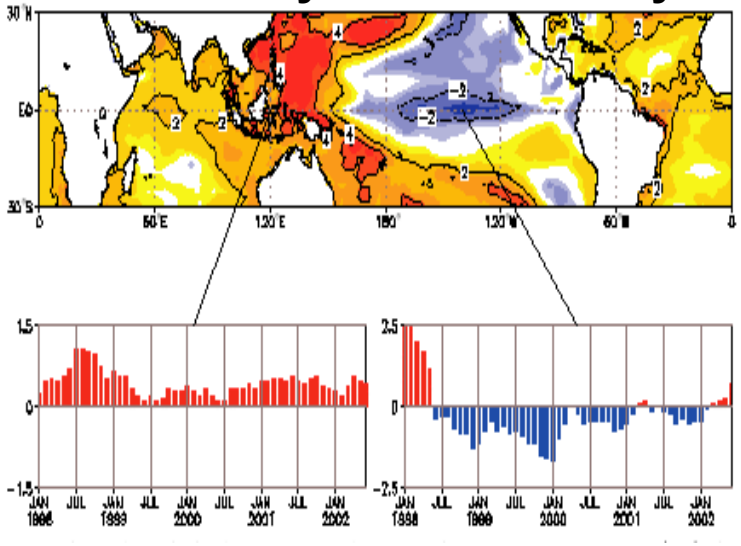
Background

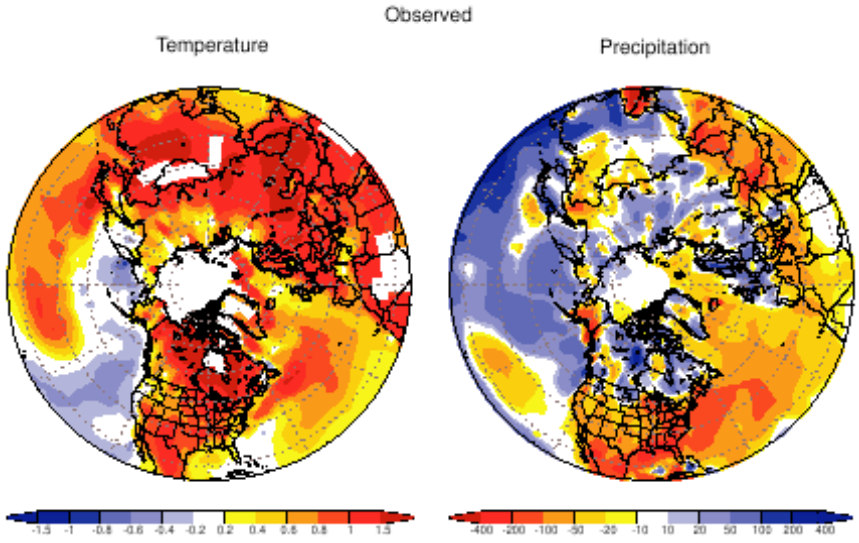
Role of the ocean in North American Climate

•**Namais**, **1969,1983,...** Discusses links between eastern Pacific SST anomalies and droughts over the United States.

•**Hoerling and Kumar 2003** Perfect ocean for drought role of Indian Ocean in creating hemisphere wide drought

SST Anomaly June 1998-May 2002

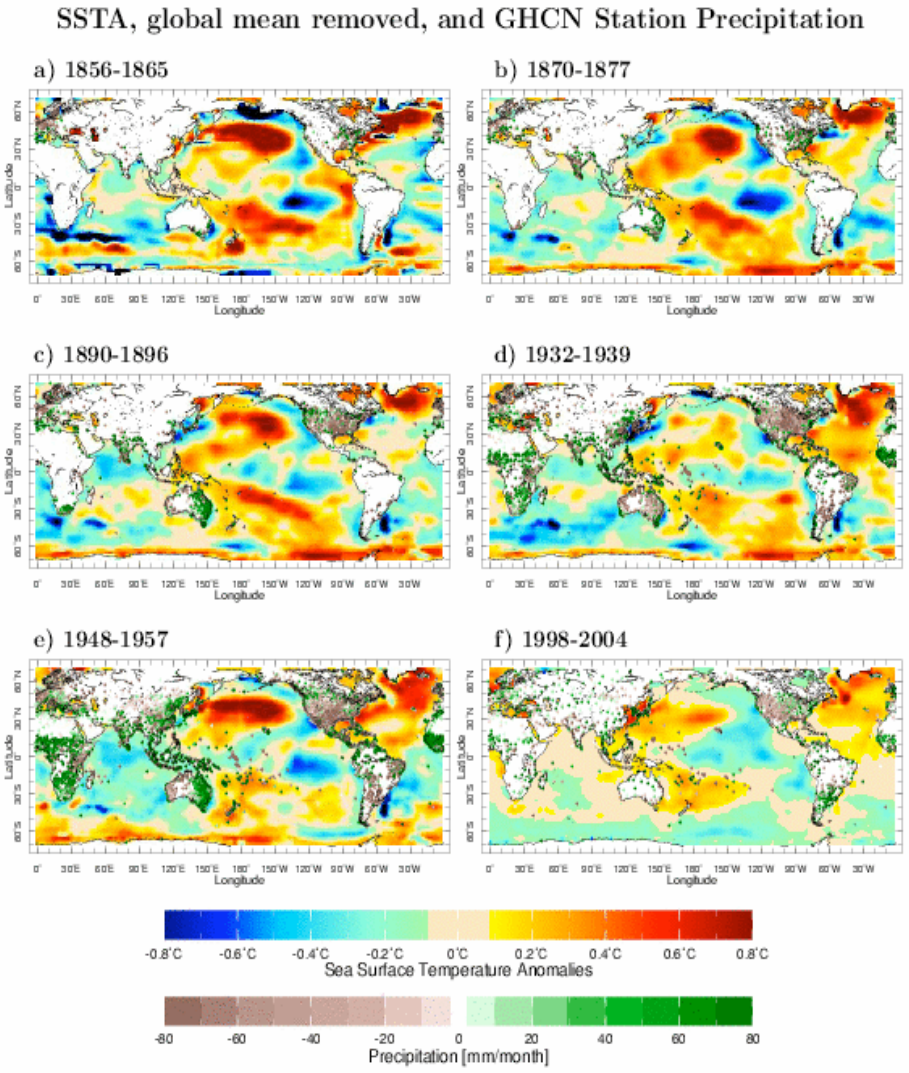




Taken from Hoerling and Kumar, Science 2003

•**Schubert et al**. **2004** Long Term drought:Pan Pacific SST anomalies are strongly tied to long term variability in Great Plain Precipitation

•**Seager 2006** Turn of the Century drought indicated by persistent La Nina, and extended across most of the NH



Taken from Seager, Journal of Climate 2006

Observed Data

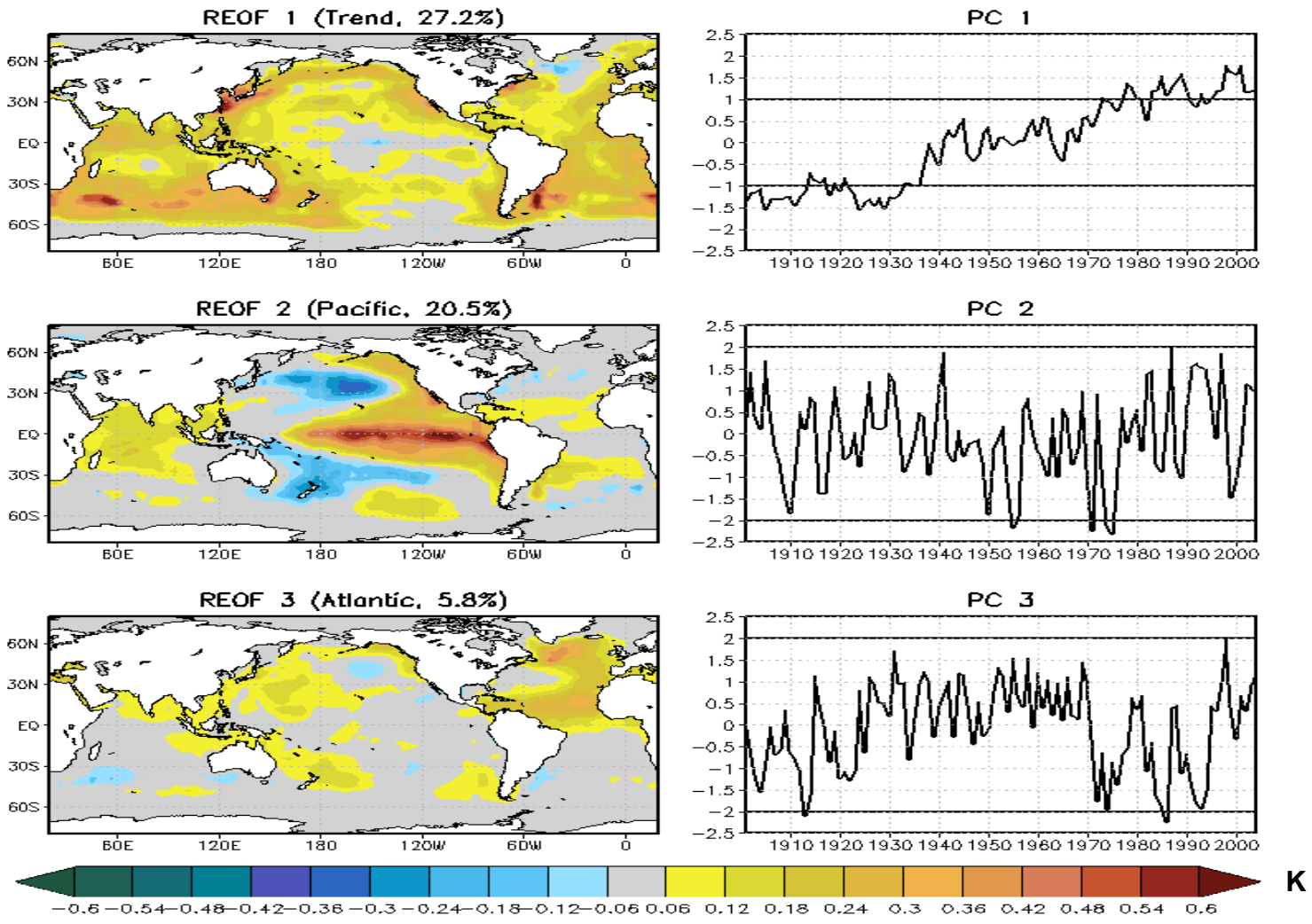
SST: HADISST (Rayner et al 2003)

ERSSTv3b (Smith and Reynolds 2003)

Temperature: HADCRUT (Parker et al. 1994, Jones et al. 2001)

Precipitation: GHCN Global Gridded Precipitation

Identification of the leading patterns of SST variabili



Linear Trend Pattern (T)

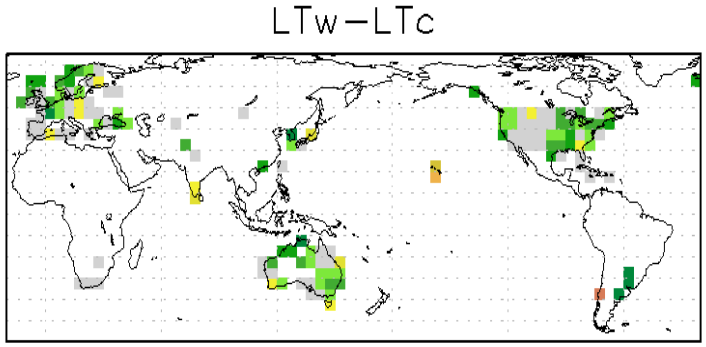
Pacific Pattern (P)

Atlantic Pattern (A)

Composite based on +/- 1 Standard Deviation of PCs

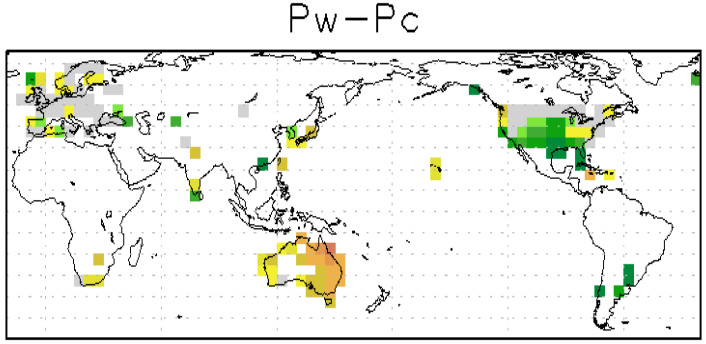
GHCN Precipitation

T (warm-cold)



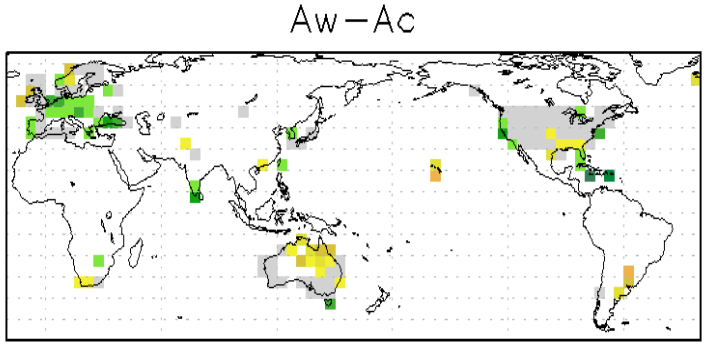
GHCN shows an increase in precipitation over most areas

P (warm-cold)

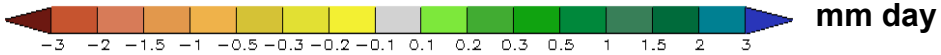


A warm pacific produces wet conditions over southern and central US.

A (warm-cold)



Weak connection of precipitation anomalies and Atlantic SSTs over the North American sector.

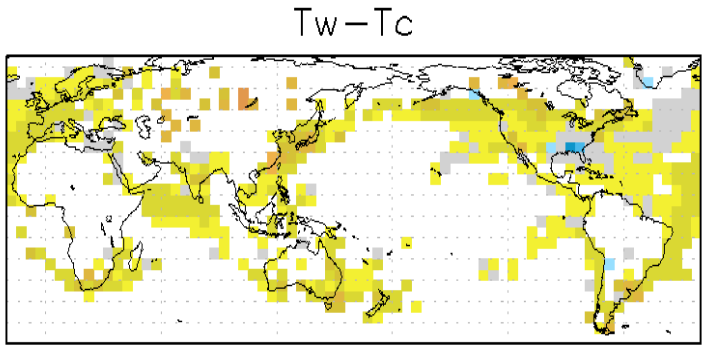


Shaded areas indicate where there are at least 35 years of data.

Composite based on +/- 1 Standard Deviation of PCs

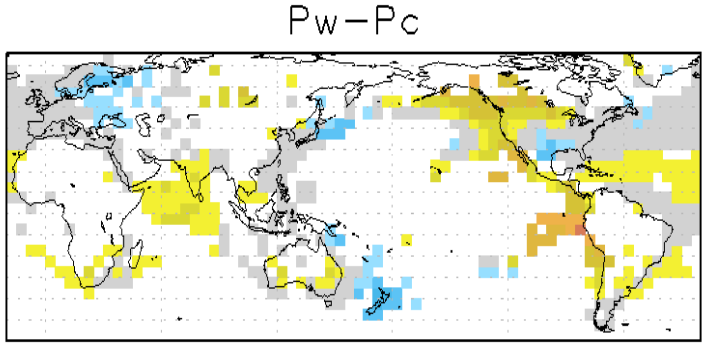
HADCRU Temperature

T (warm-cold)



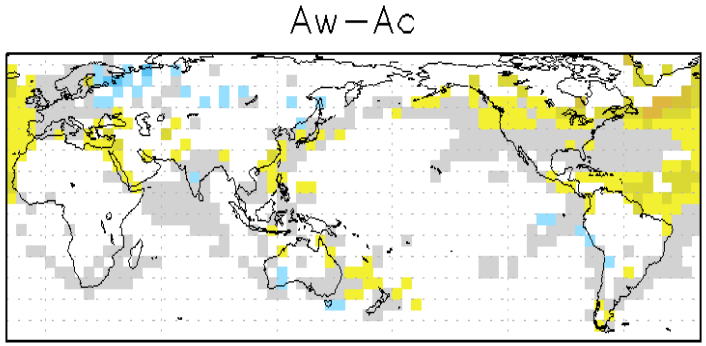
HADCRU shows an increase in temperature globally, with the exception of southeastern U.S.

P (warm-cold)



A warm pacific produces warm anomalies over the northern and western parks of North America. Negative anomalies are apparent over eastern Europe.

A (warm-cold)



A warm Atlantic is associated with positive temperature anomalies across Canada and northern tier of the US.

K

Shaded areas indicate where there are at least 35 years of data.

Observations do not tell us enough.

Due to the non-uniform and spotty coverage of observations over the past century, it is difficult to get a complete picture of the relationship between SSTs and precip/surface temp.

Therefore, we need to turn to global models to help us understand the relationship.

Drought Working Group

Formed in December 2006

•Propose a working definition of drought and related model predictands of drought

•Coordinate evaluations of existing relevant model simulations

•Suggest new experiments (coupled and uncoupled) designed to address some of the outstanding uncertainties mentioned above

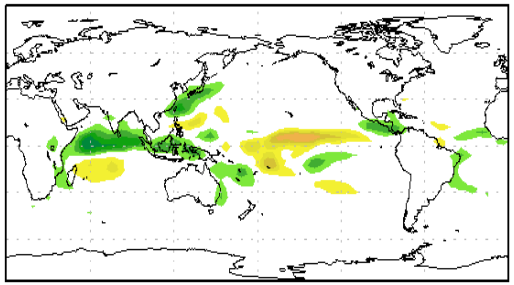
•Coordinate and encourage the analysis of observational data sets to reveal antecedent linkages of multi-year drought

•Organize a community workshop to present and discuss the results

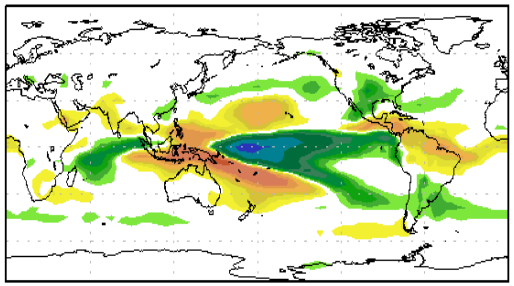
Composite based on +/- 1 Standard Deviation of PCs

Model Precipitation

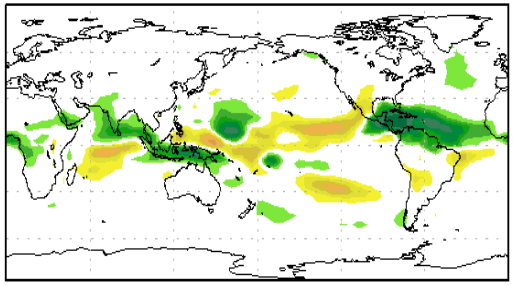
LTw−LTc



Pw−Pc



Aw−Ac



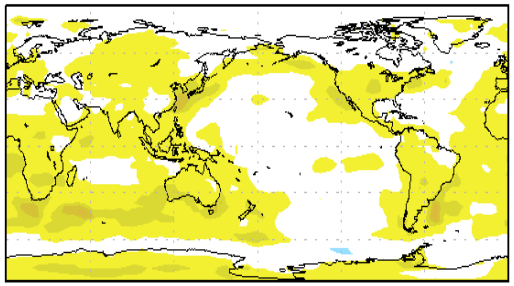
LT (warm-cold)

Pac (warm-cold)

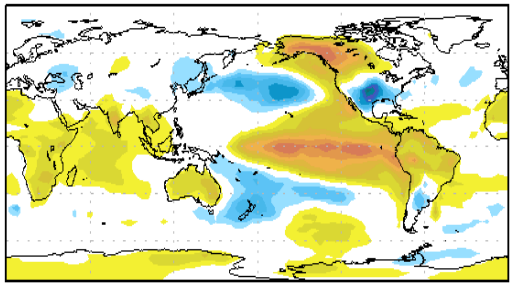
Atl (warm-cold)

Model Temperature

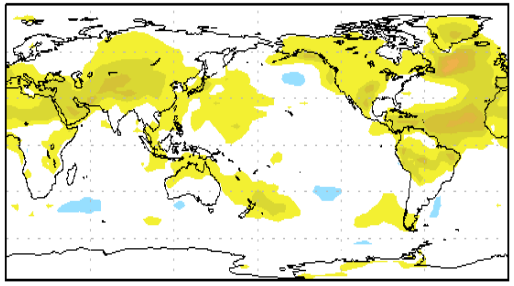
LTw−LTc



Pw−Pc



Aw−Ac



AMIP composite based on NSIPP1,GFDL,CCM3 provides a more complete picture

Drought Working Group Experiments

Several modelling groups would do identical experiments to address issues of model dependence on the response to SSTs (and the role of soil moisture), and to look in more detail at the physical mechanisms linking the SST changes to drought.

Aim was to carry out runs of 50 years over a repeating seasonal cycle of each pattern, and various combinations of the patterns generated from the first three rotated EOFs.

Models:	NASA	**NSIPP1**
	Lamont	**CCM3**
	NCEP	**GFS**
	GFDL	**AM2.1**
	NCAR/Univ. MD	**CAM3.5**
	COLA/Univ. of Miami	**CCM3.0**, not included in this presentation.

Design of experiments

The rotated EOF patterns of SSTs are scaled by +/- 2 standard deviations of the PC, and added to a seasonally varying climatology.

The AGCMs are then run with these various SST patterns and various combinations (15 in total, only 6 are shown here).

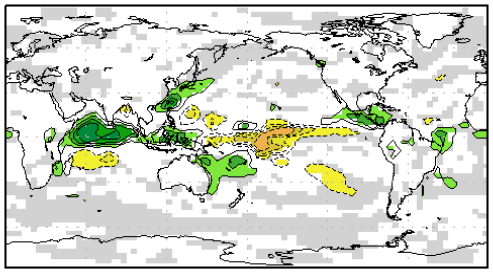
Models ran for 51-years (36 for GFS) for each pattern.

Multi-model Annual mean (warm – cold) response.

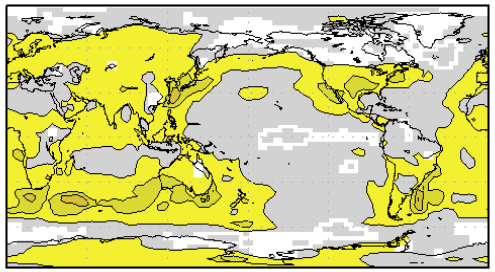
Precipitation

Surface Temperature

Tw – Tc

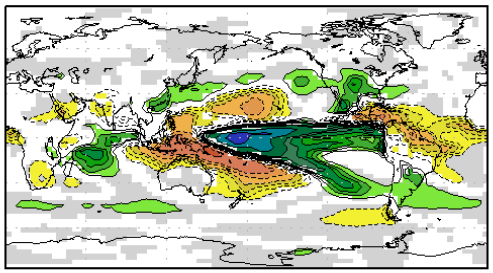


T (warm-cold)

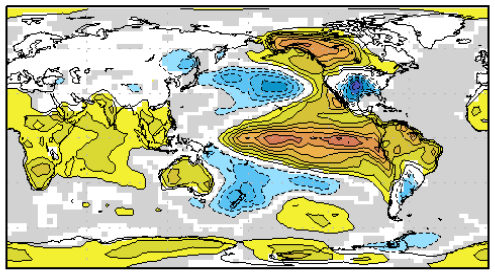


Tw – Tc

Pw – Pc

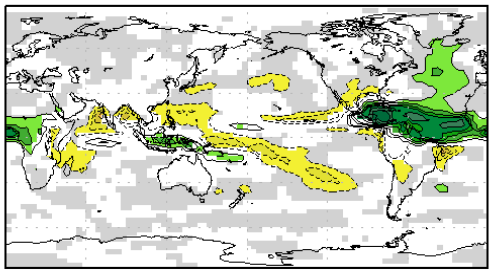


P (warm-cold)

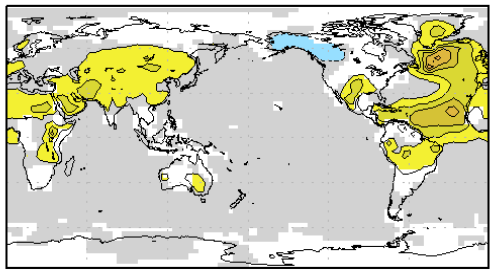


Pw – Pc

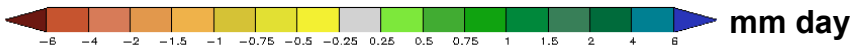
Aw – Ac



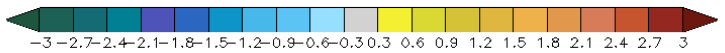
A (warm-cold)



Aw – Ac



mm day



K

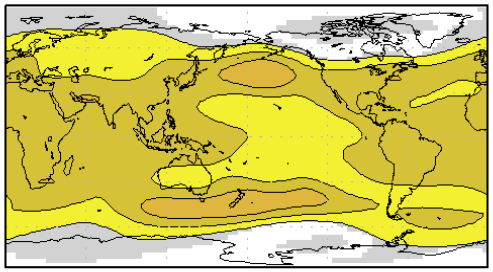
Shading indicates where at least 4 out of the 5 models have the same sign response.

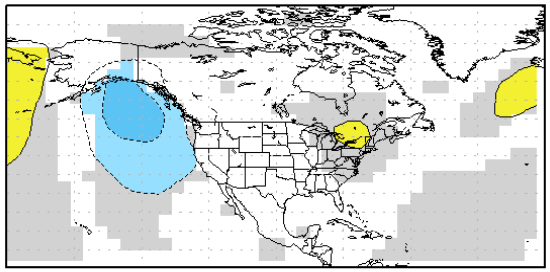
Multi-model Annual mean (warm – cold) response.

200 mb Height

850 mb V-wind

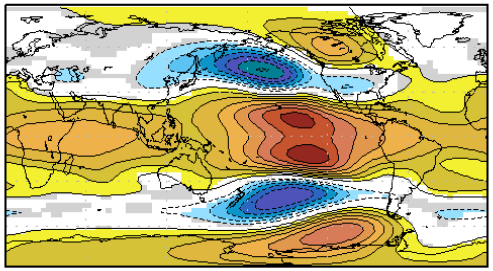
LTw – LTc

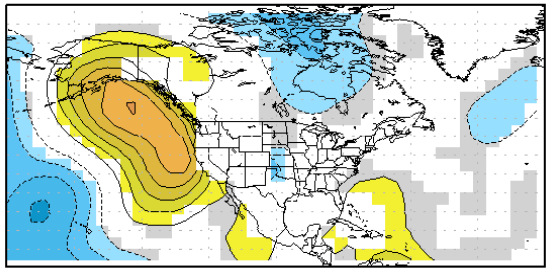




T (warm-cold)

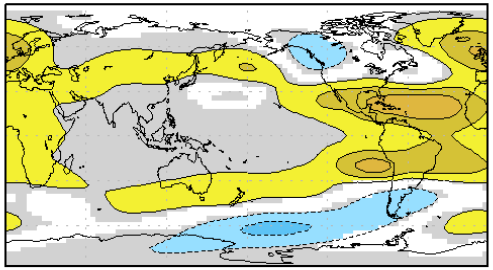
Pw – Pc

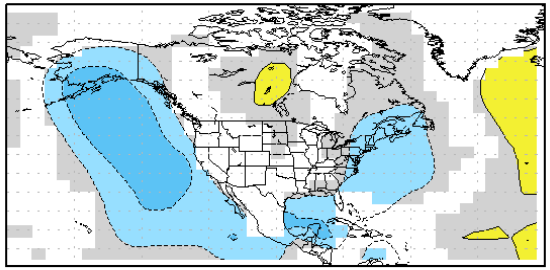




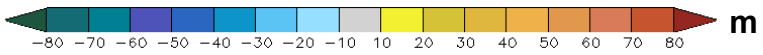
P (warm-cold)

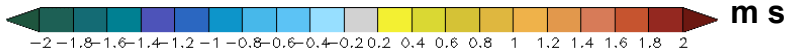
Aw – Ac





A (warm-cold)

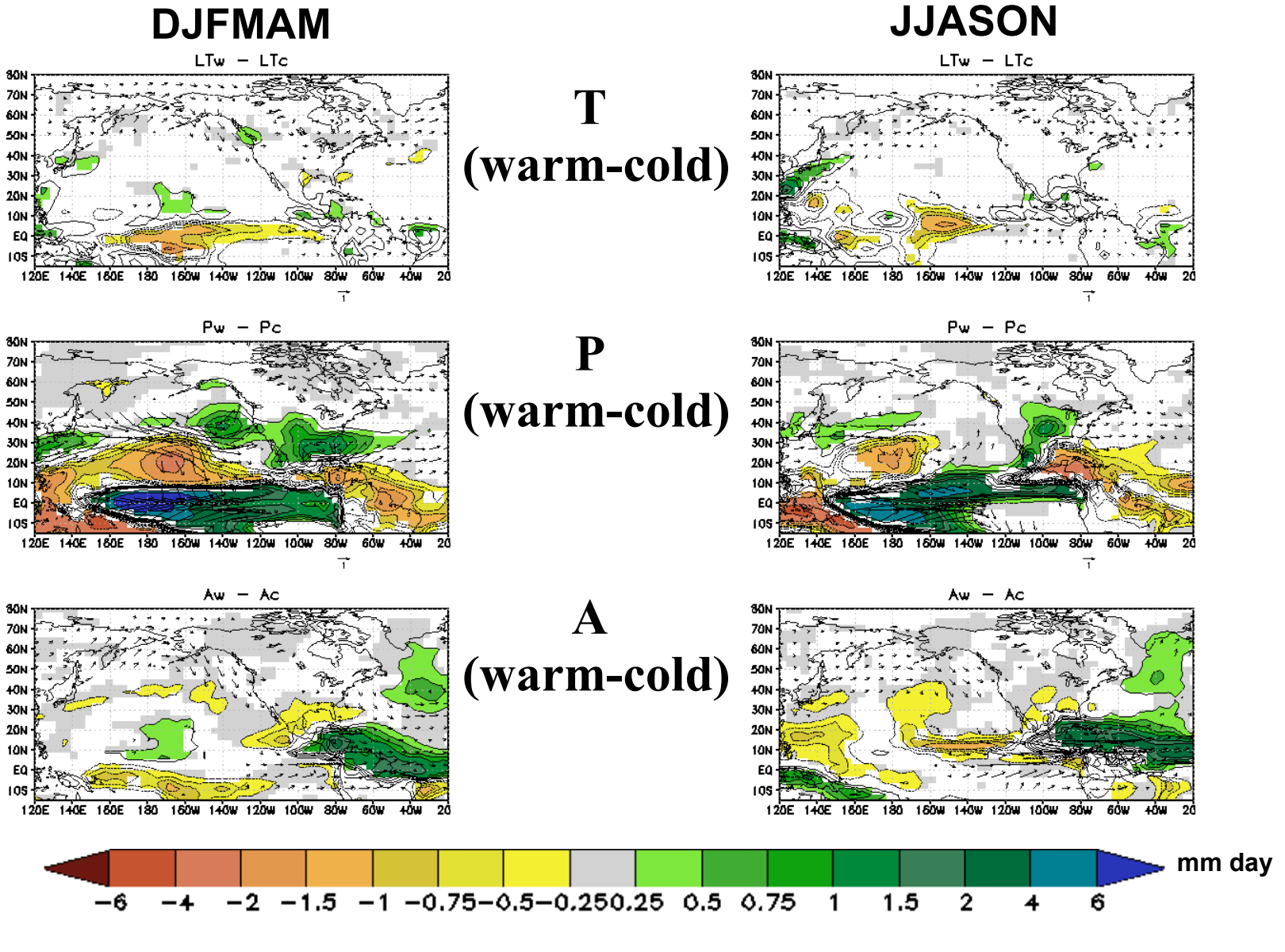




Shading indicates where at least 4 out of the 5 models have the same sign response.

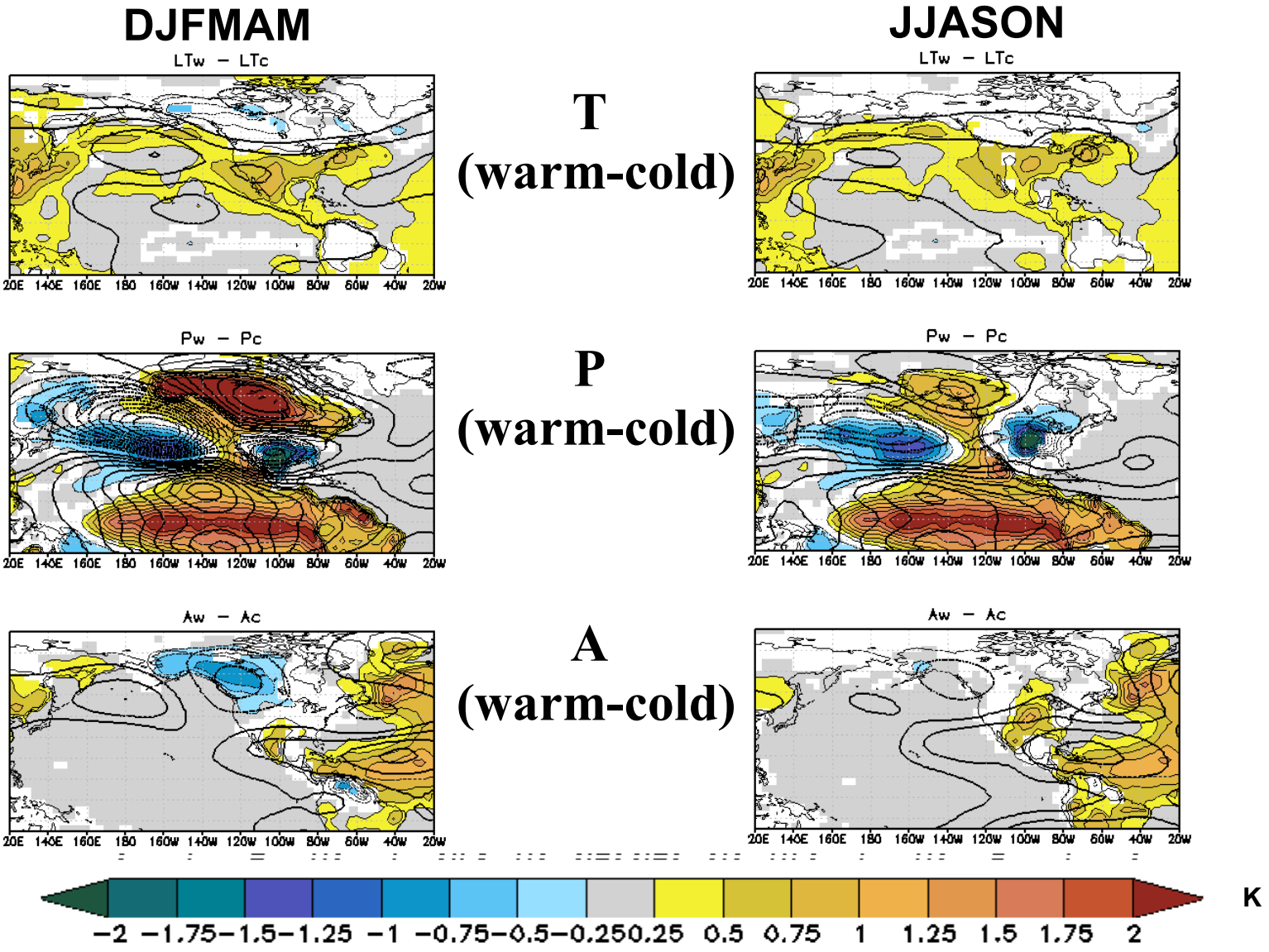
Seasonality of the Response

Precipitation (shaded) & 850 mb winds (contour)

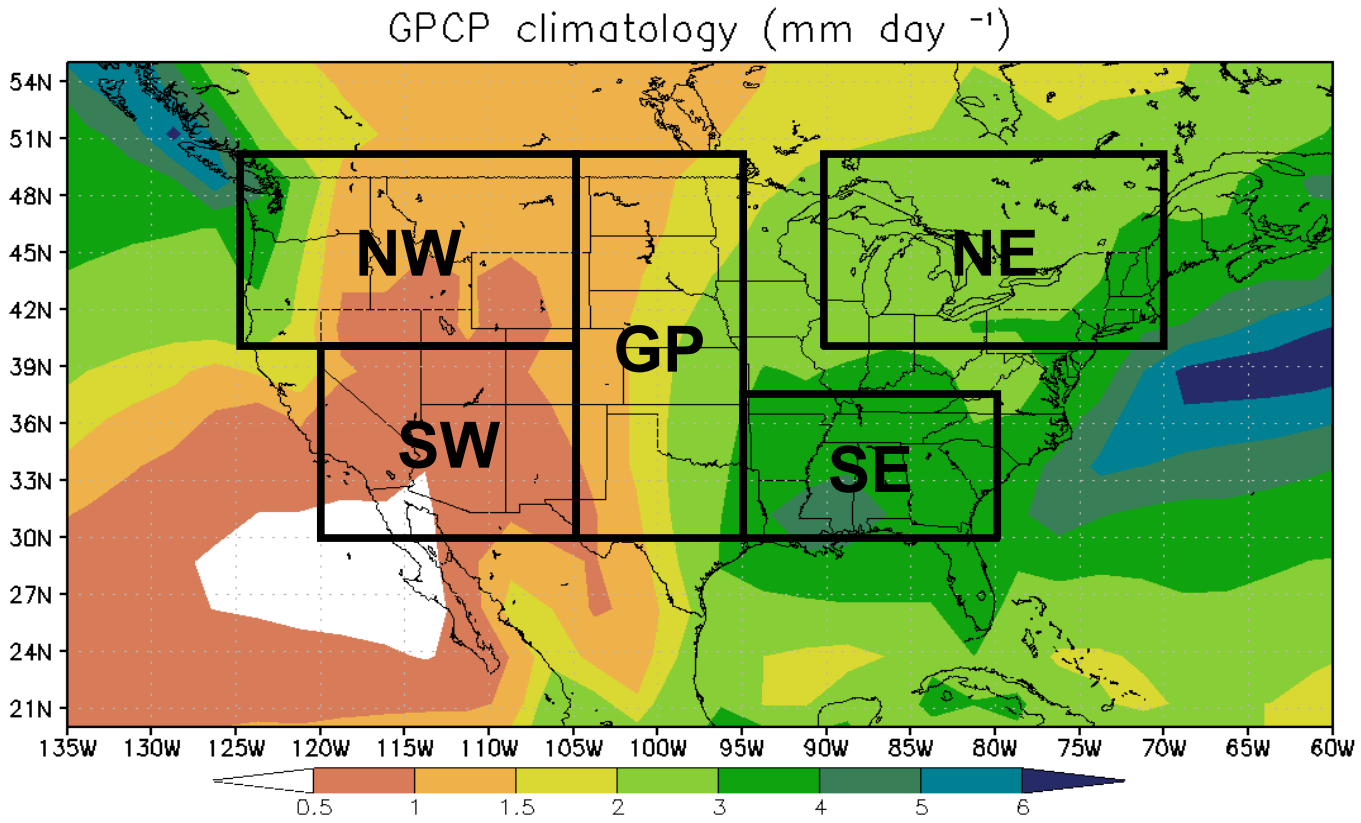


Seasonality of the Response

Surface Temperature (shaded) & 200 mb Height (contour, 10m interval)



Some regional highlights



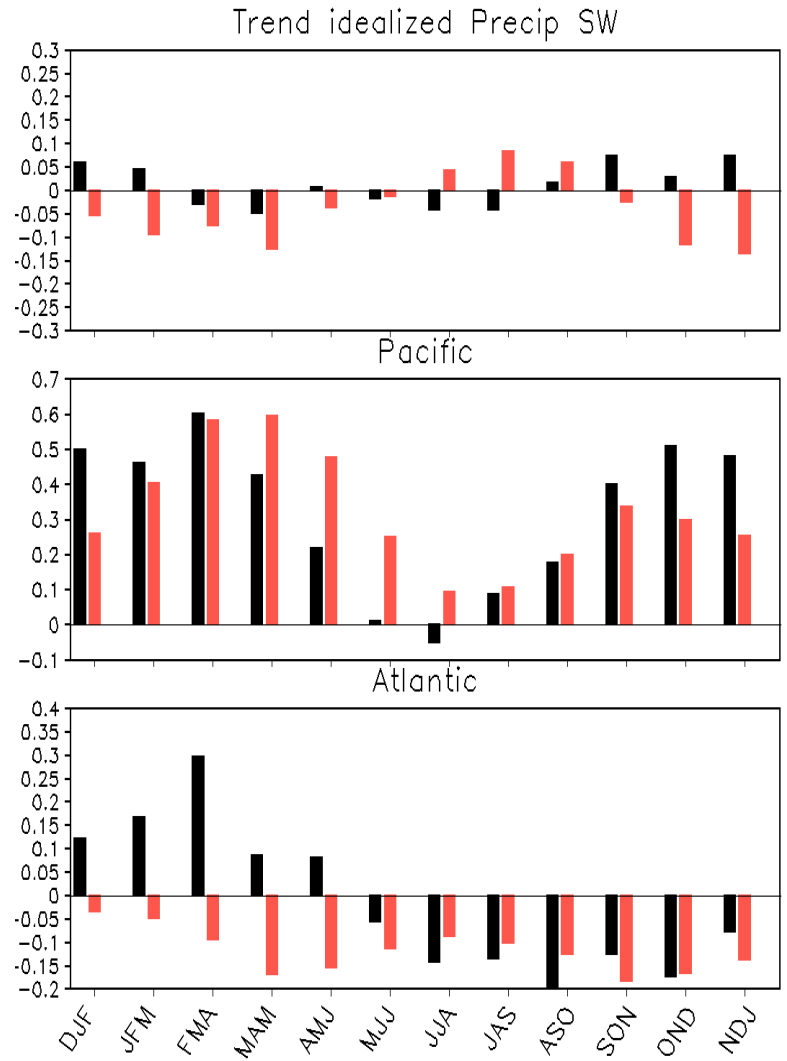
Seasonal Anomalies for South Western US (30-40N,105-120W)

Precipitation

LT
(warm-cold)

Pac
(warm-cold)

Atl
(warm-cold)



Black: GHCN

Red: Multi-Model Mean

Seasonal Anomalies for South Western US (30-40N,105-120W)

Surface Temperature

LT
(warm-cold)

Pac
(warm-cold)

Atl
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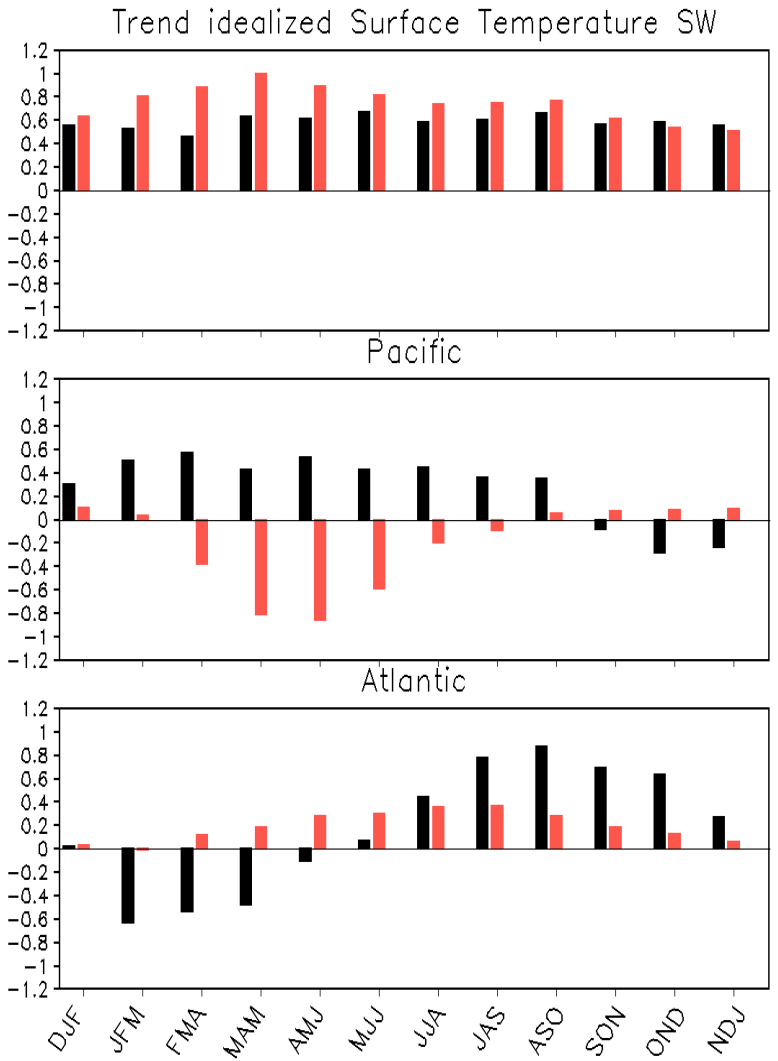


Black: HADCRUT

Red: Multi-Model Mean

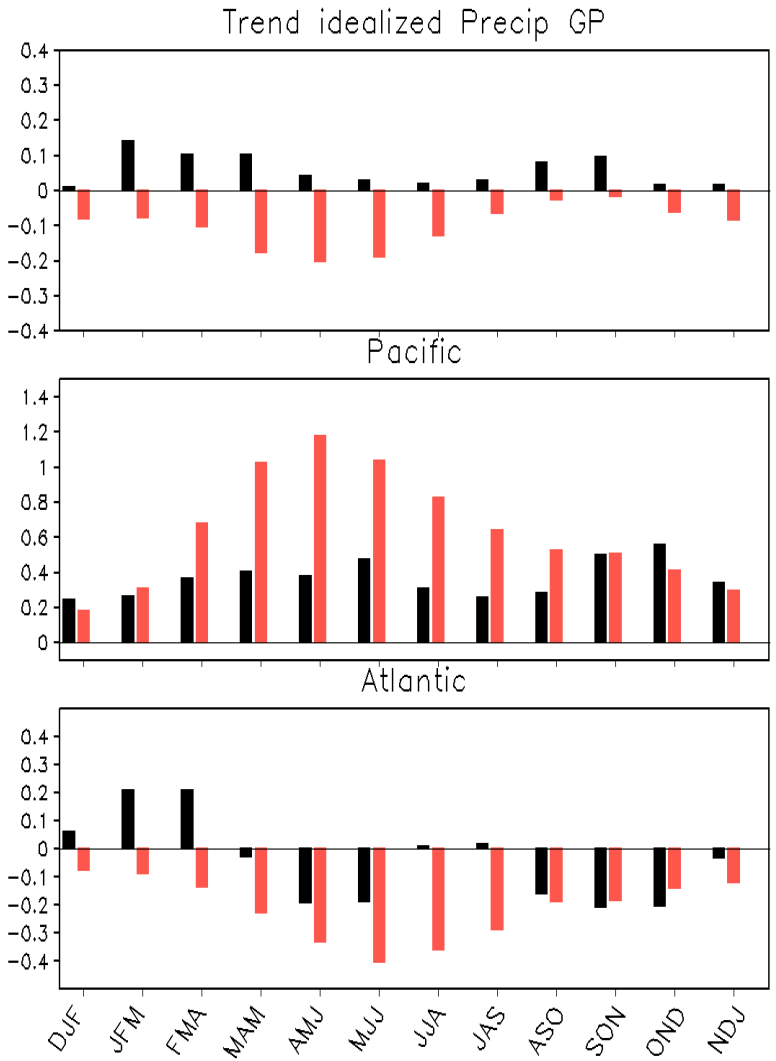
Seasonal Anomalies for US Great Plains (30-50N,95-105W)

Precipitation

LT
(warm-cold)

Pac
(warm-cold)

Atl
(warm-cold)



Black: GHCN

Red: Multi-Model Mean

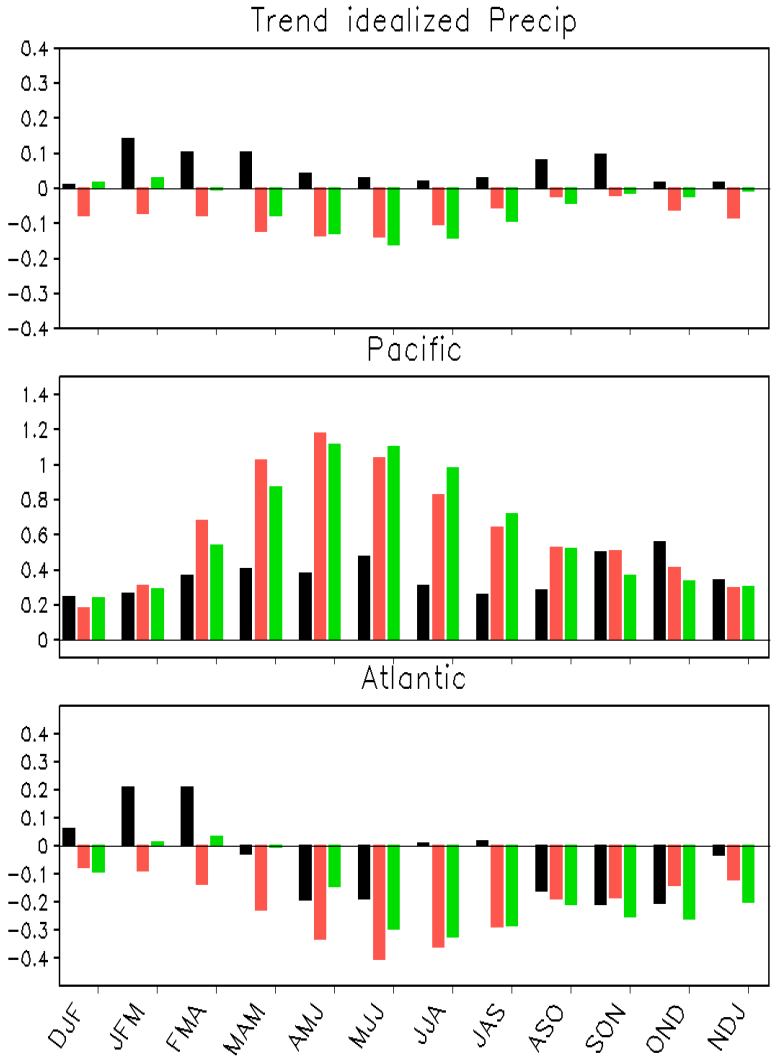
Seasonal Anomalies for US Great Plains (30-50N,95-105W)

Surface Temperature

LT
(warm-cold)

Pac
(warm-cold)

Atl
(warm-cold)



Black: HADCRU **Green: AMIP** **Red: Multi-Model Mean**

All of the focus so far has been on the mean response, but that is just a mathematical value.

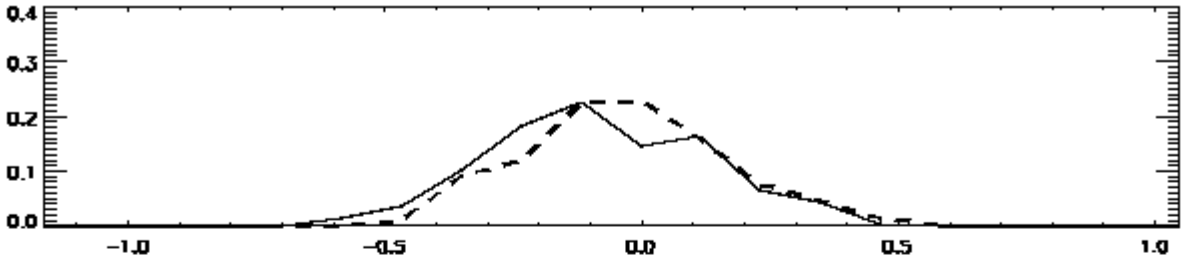
What we see in the real world is a single realization, which contains a SST forced signal and unrelated noise.

Therefore, we need to look at all of the individual years to understand how these SST patterns really affect drought.

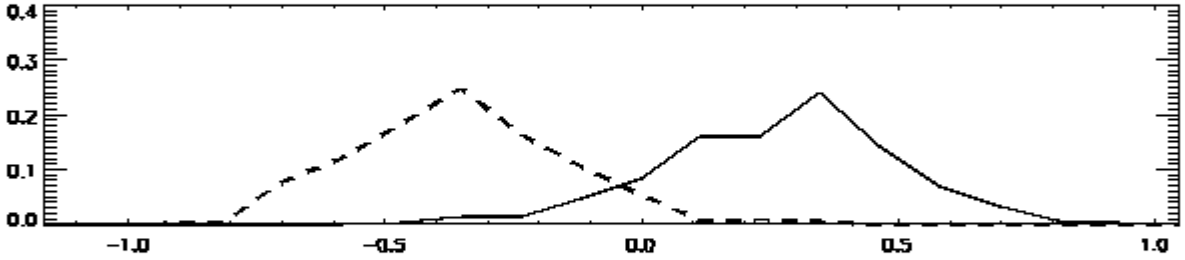
US Great Plains (95W-105W, 30N-50N)

PDF of annual mean precipitation

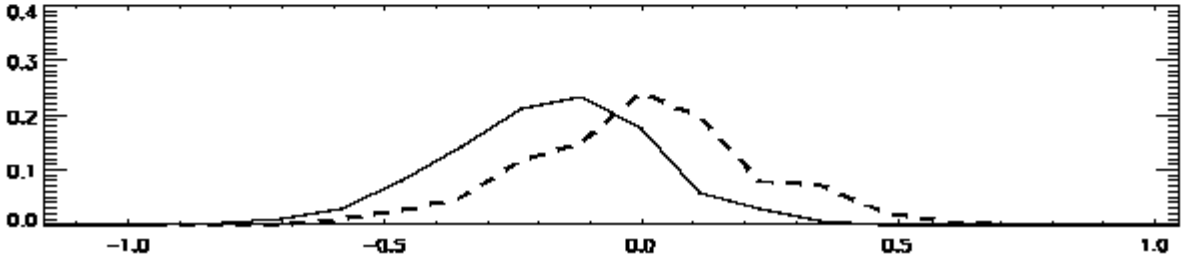
Trend



Pacific



Atlantic



Positive SST forcing

Negative SST forcing

Chance of having 3-years in a row with below average precipitation

Region

SST forcing

	NW	SW	NE	SE	GP
LTw	9.0	22.9	9.3	19.8	19.7
LTc	15.5	13.0	17.4	9.9	10.6
Pw	6.5	0.4	3.5	1.5	3.4
Pc	18.2	51.2	24.9	43.6	53.0
Aw	9.4	38.8	15.9	26.1	38.2
Ac	19.6	7.4	8.4	6.1	12.5
Clim	15.6	18.1	12.2	9.2	9.3

Percentages are calculated by bootstrapping each response 10,000 times and counting the number of cases where all three years had negative (positive) precipitation anomalies

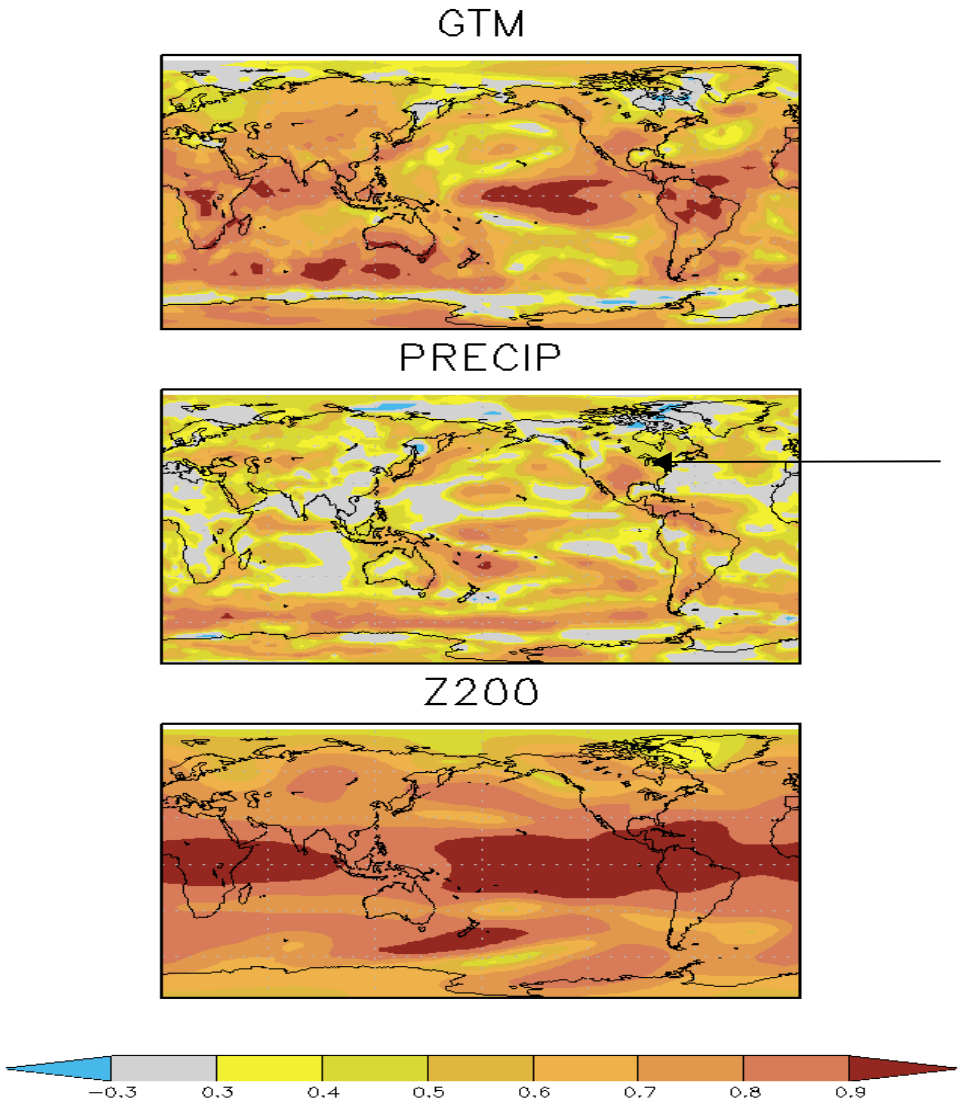
How do relate these idealized experiments results to actual SST variability?

Assuming the responses to these three patterns of SST are linear.

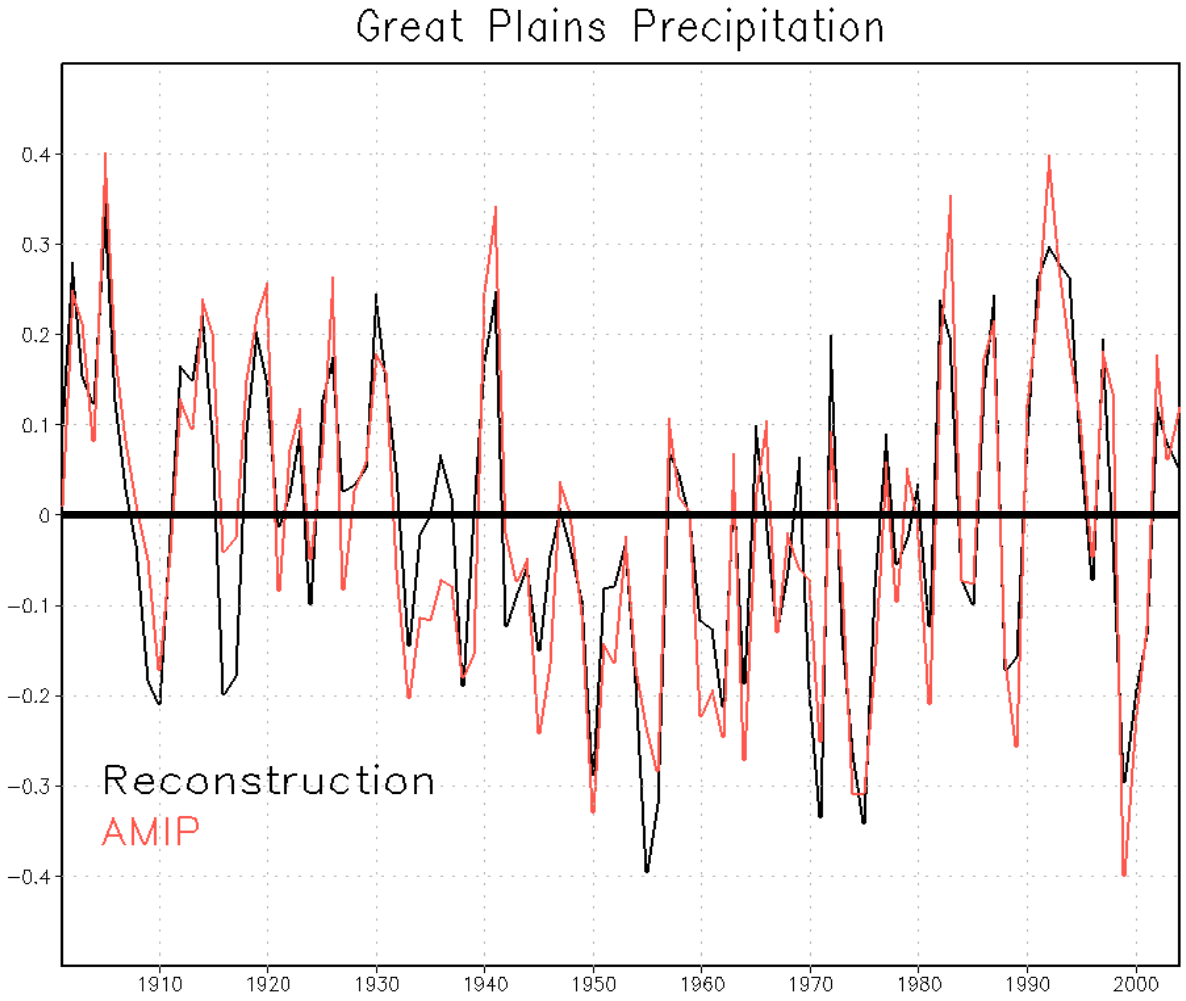
The precipitation responses to the three patterns are scaled by the principal component for each year to re-create the SST forced precipitation over the 20th Century.

In effect, this can be considered analogous to an EOF truncation, but of the response.

Correlation of Annual Means from the AMIP runs and scaled linear responses from the idealized experiments

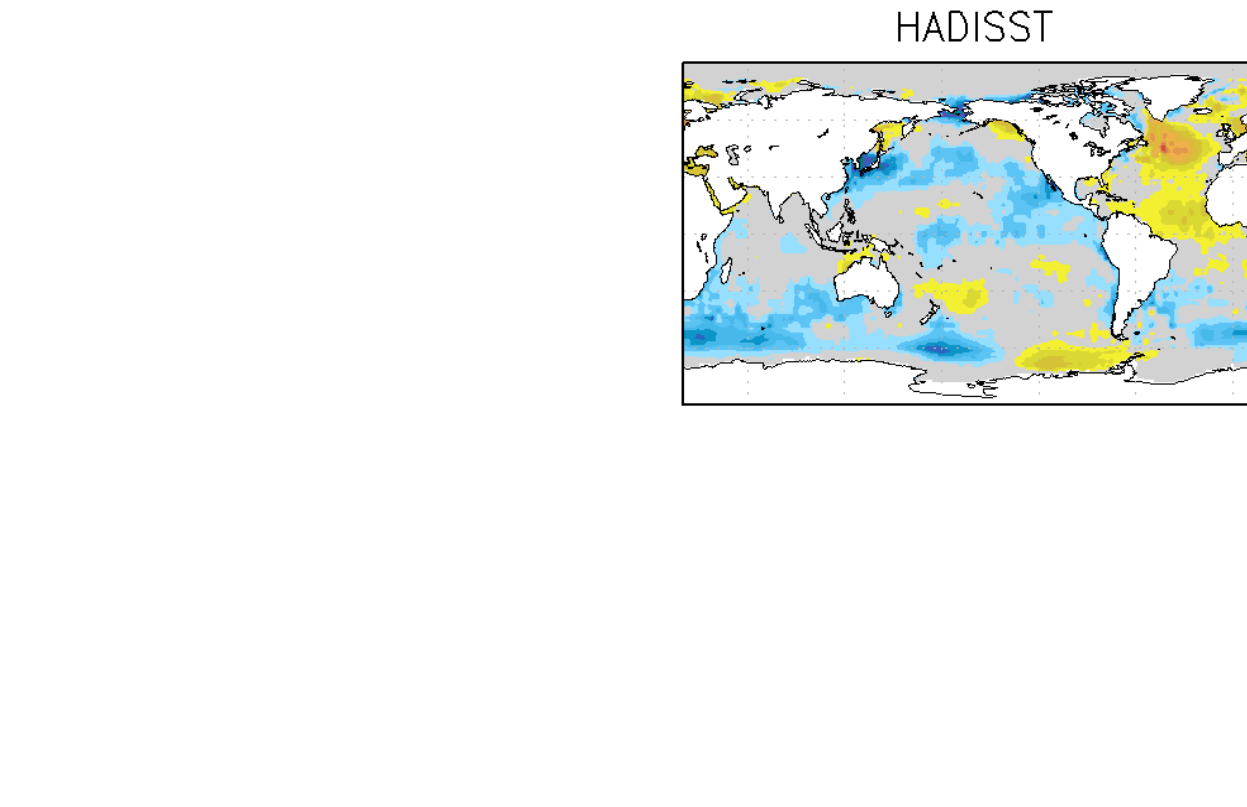


Central US has one of highest correlations in the mid-latitudes.



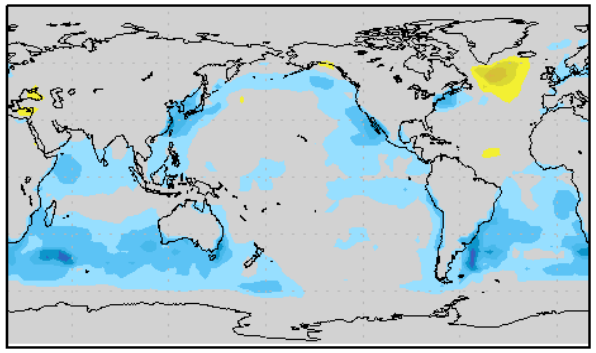
AMIP precipitation anomalies are largely explained by the 1st 3 EOFs. One notable exception is the 1930s, the Dust Bowl period.

SST anomaly average 1932-1938

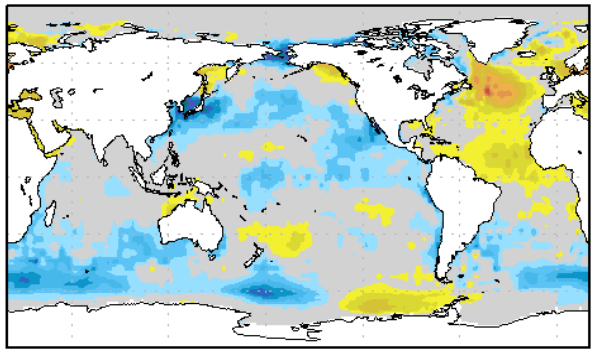


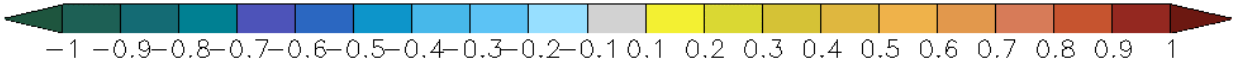
SST anomaly average 1932-1938

Reconstuction



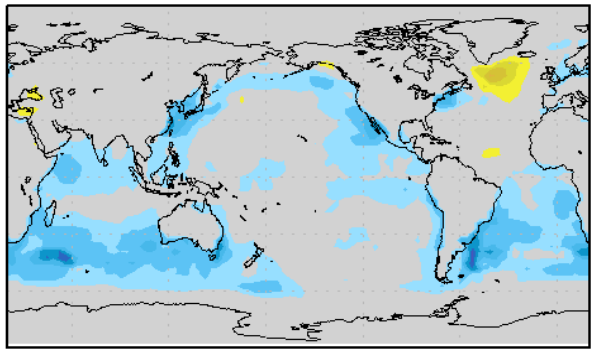
HADISST





SST anomaly average 1932-1938

Reconstuction



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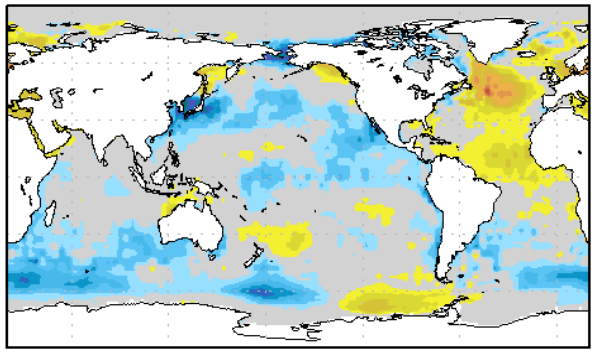
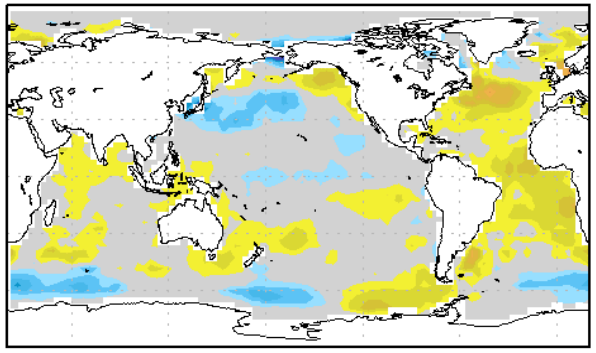
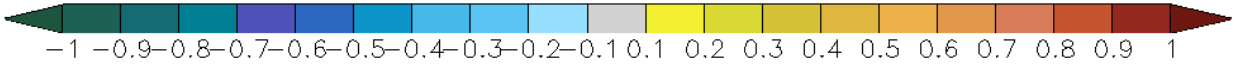
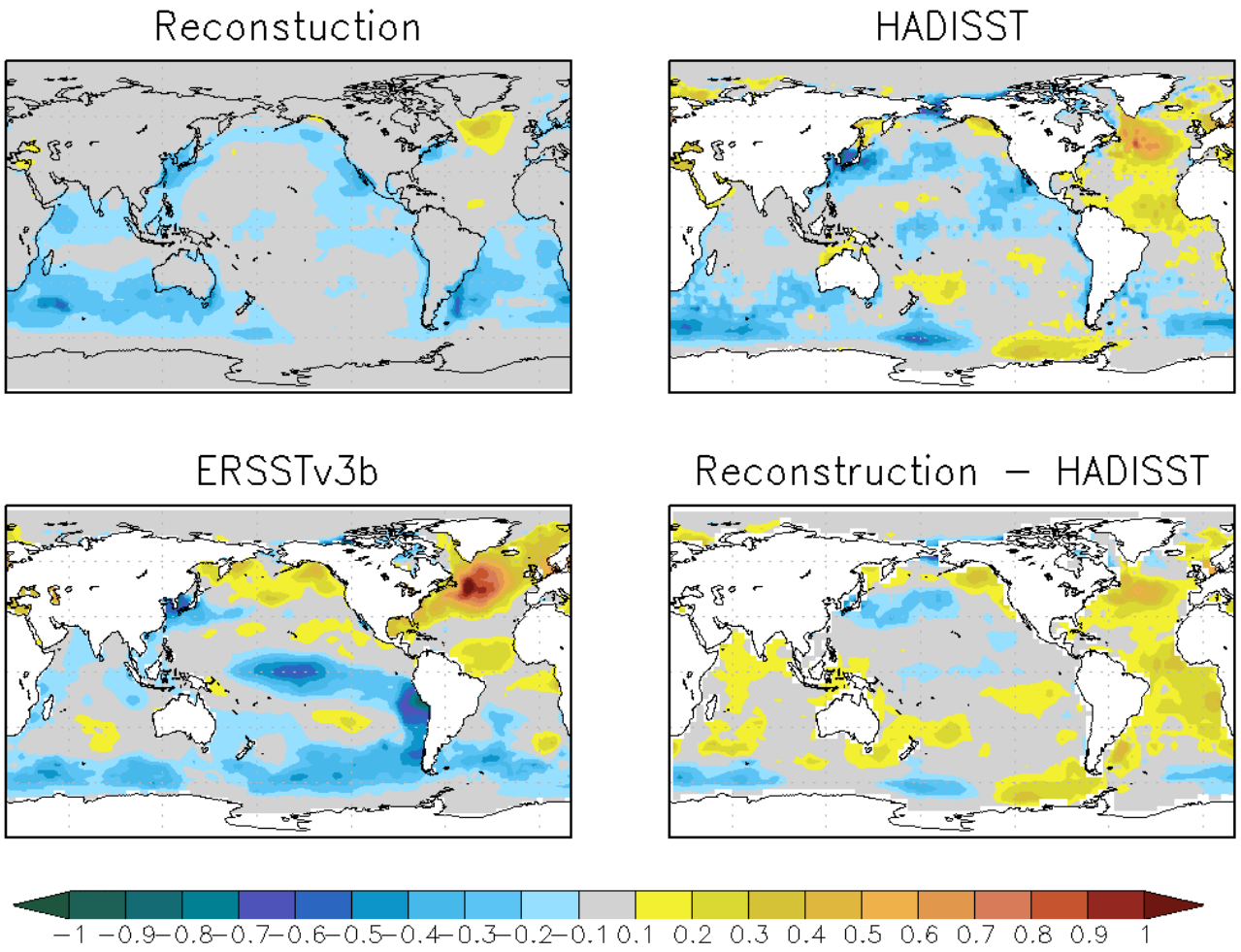


Reconstruction – HADISST





SST anomaly average 1932-1938



Other issues...

- Even if low-frequency variations in SSTs have global impacts of societal importance, can such SSTs themselves be predicted?
- Answer to this question is being explored via coordinated decadal prediction experiments
  - Initialized decadal prediction experiments as part of the IPCC-AR5 (due to be released in 2013)
  - **10 year integrations** with initial dates towards the end of 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 2000 and 2005 (initial conditions?)

Conclusions

- The 3 leading patterns of SST variability each affect the temperature and precipitation over the United States.
- Even though the anomalous SST forcing is fixed in time, there is a seasonal cycle to the response to these anomalies.
- The response to the SST patterns appears to be additive. Regression of AMIPs and idealized experiments give similar results.
- SST anomalies that occurred during the 1930s dust bowl is not associated with these 3 leading EOFs.
- 1930s SST in the ERSST is very different, giving uncertainty to our explanation of the droughts over the 20th century.

Seasonality of the non linear Response

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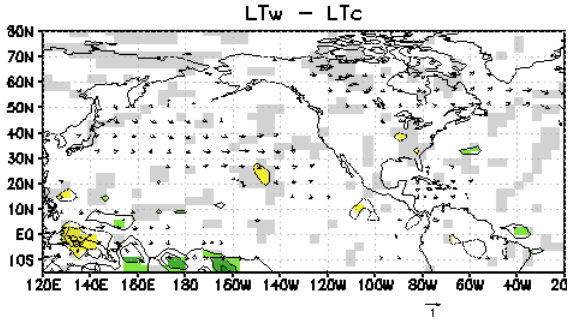
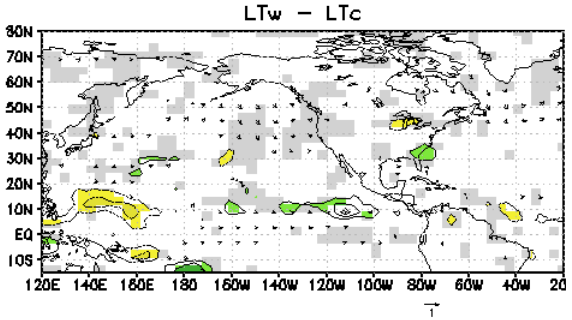
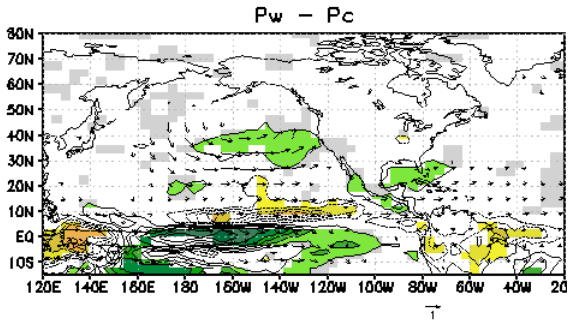
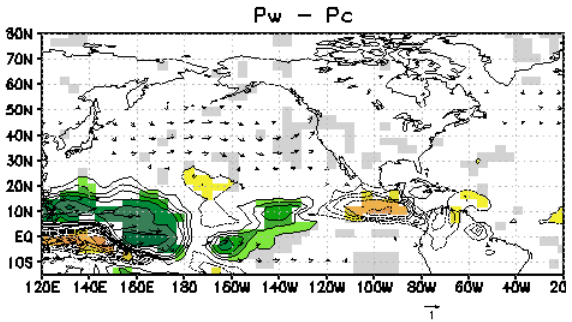
T (warm-cold)



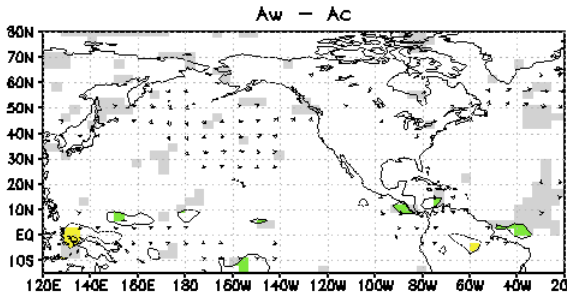


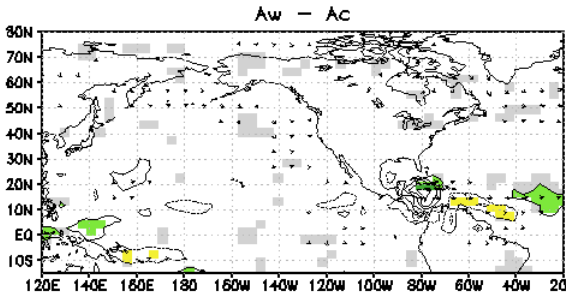
P (warm-cold)

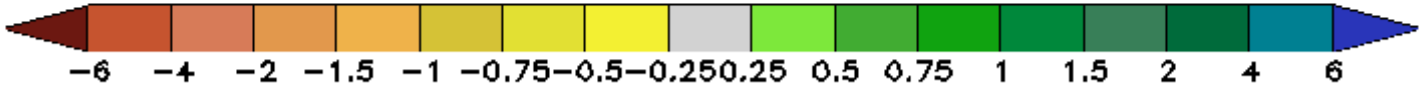




A (warm-cold)







Seasonality of the non linear Response

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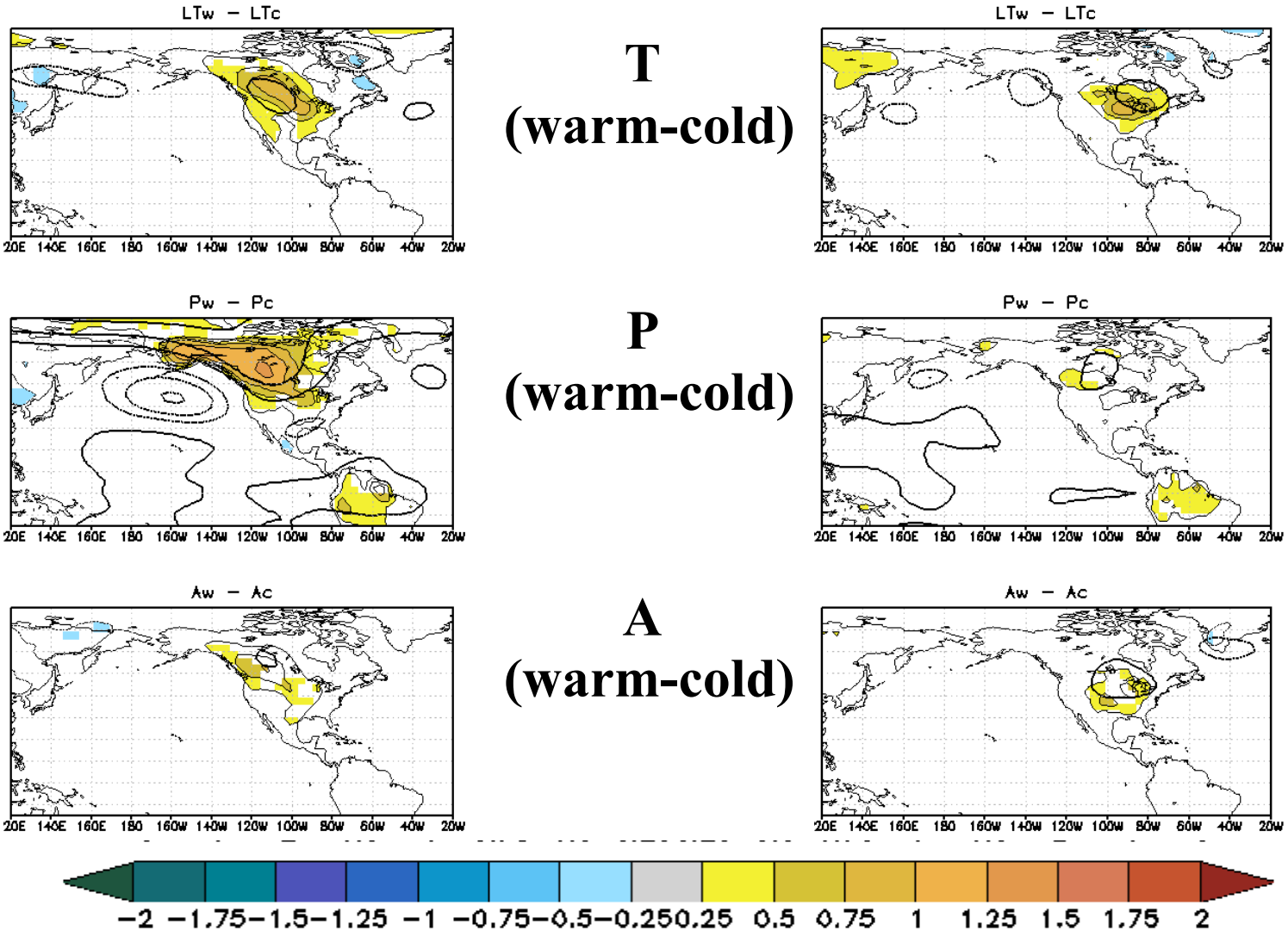


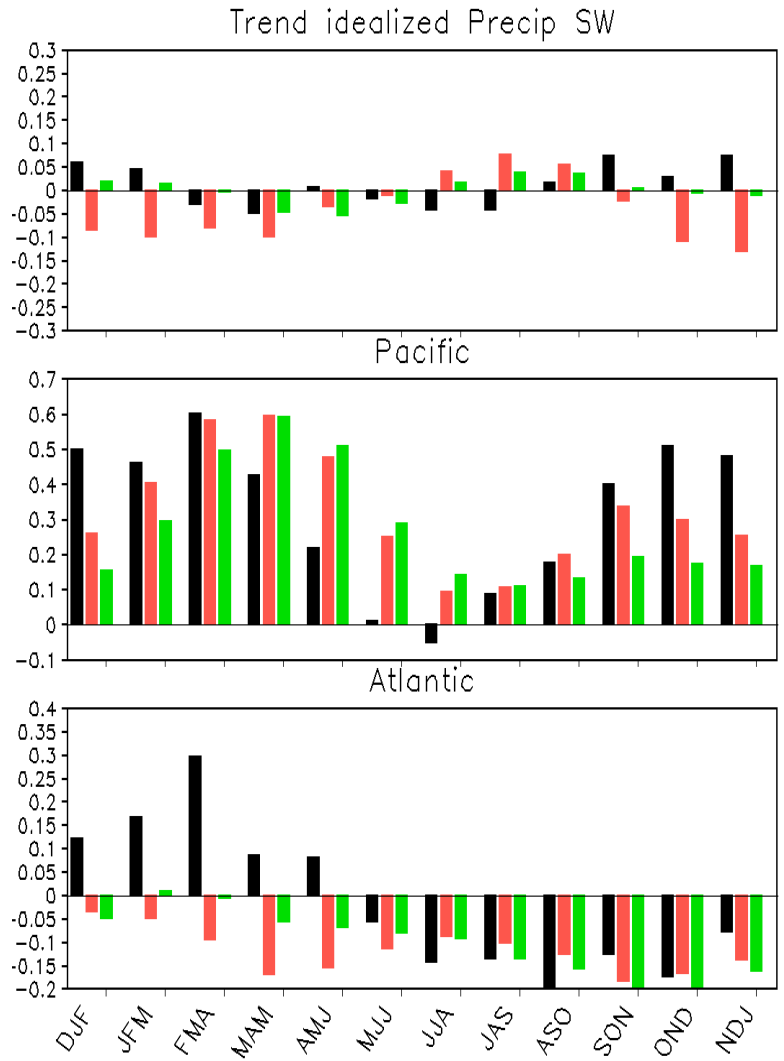
Seasonal Anomalies for South Western US (30-40N,105-120W)

Precipitation

LT
(warm-cold)

Pac
(warm-cold)

Atl
(warm-cold)



Black: GHCN **Green:AMIP** **Red: Multi-Model Mea**